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Development of

HIGH-TEMPERATURE, GAS-FILLED, CERAMIC RECTIFIERS, THYRATRONS, AND VOLTAGE-REFERENCE TUBES

by

E. A. Baum

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Quarterly Progress Report No. 2

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Development of

HIGH-TEMPERATURE GAS-FILLED CERAMIC RECTIFIERS, THYRATRONS, AND VOLTAGE-REFERENCE TUBES

by E.A. Baum

SUMMARY

Contract NAS3-6469 is a continuation of the work effort started under Contract NAS3-2548 for the development of high-temperature ceramic rectifiers, thyratrons and voltage-reference tubes for long-term use in nuclear electric space power systems. The present phase of the program is directed at establishing the validity of the high-temperature tube technology and design concepts developed up to this time.

Five ceramic thyratrons have been fabricated, and are now being processed. The first thyratron put on test was operated for only three hours at 600°C to 650°C when a leak developed in the brazed joint between the exhaust tubulation and the anode assembly. During this period, the tube was operated at up to 10 amperes average current at 60 cycles.

A second thyratron of the same design configuration was put on test and operated for 80 hours at temperatures above 600°C wall temperature. The maximum operating temperature was limited to 700°C. Approximately 10 to 15 hours of the total test time was at 3000 cycles. The tube was still operable after this time but was removed from the test station to commence tests on tube No. 3. The results of the tests on tube No. 2 are discussed in the body of this report. Tubes No. 3 and 4 are of the same initial design. Tube No. 5 has the same cathode and grid assembly, but was fabricated with a hollow anode structure.

In separate test situations, the maximum dynamic conditions under which tube No. 2 was operated are the following:

		A	B
Wall Temperature	-	$650^{\circ}C$	$730^{\circ}C$
Anode Temperature	-	$635^{\circ}C$	$800^{\circ}C$
Average Current	-	3.0 amperes	15.0 amperes
Peak Inverse Voltage	-	1700 volts	175 volts
Peak Current	-	9.5 amperes	47.0 amperes

The low current value at the high peak inverse voltage was due to limitations of the high-frequency supply, not the tube characteristics. Static DC characteristics were taken for tube temperatures of $550^{\circ}C$, $600^{\circ}C$, $650^{\circ}C$, $700^{\circ}C$, and anode voltages up to 2000 volts DC. A single nine-hour run was made at 3000 cycles, 2 amperes average, and 1500 volts peak inverse with a tube wall temperature of $600^{\circ}C$. Subsequent tests were also made at 15 amperes average current and 175 volts peak inverse from 400 cycles to 3000 cycles.

A finned-cathode structure has been so designed that the cathode heater is external to the tube. This cathode has an area of 70 square centimeters as compared to the 25-square-centimeter cathode presently in use. The average current capability of the larger cathode is in excess of 15 amperes.

The endurance test stations for the voltage-reference tubes are essentially complete. The first set of tubes for the 1000-hour operational tests have been processed and are ready for mounting in the test station.

INTRODUCTION

The work effort during the first quarter of the high-temperature tube program was directed toward the design and initial fabrication of the high-temperature ceramic thyratron and voltage-reference tubes. The initial tube designs were shown in Figures 1 and 3 of the first quarterly report. The effort in the second quarter was directed at completing fabrication of the first five thyratrons and initiating the performance test program of both tube types.

The tubes fabricated during this program are being given a series of electrical, mechanical, and endurance tests. The electrical tests are being conducted over a frequency range of 400 to 3200 cycles per second, and in a vacuum environment at temperatures in the range of 200°C to 800°C. Five tubes of each type will be given endurance tests at the highest temperatures compatible with tube performance. Each endurance test will be a minimum of 1000-hours duration.

TECHNICAL DISCUSSION AND PROGRESS

THYRATRON DESIGN

The initial design of the high-temperature thyratron is shown in Figure 1. In this structure, the cathode heater connection is brought out through a ceramic pin feedthrough welded into the cathode header. A modification of this design has been made such that the heater lead connection is brought out directly through the cathode header. Figure 2 is a photograph of a completed tube prior to exhaust. The wide center flange is the grid support and seal. A threaded stud is brazed onto the Fernico tubulation and serves as the anode lead connection. The glass on the end of the exhaust tubulation is used to electrically isolate the anode while it is on the exhaust and gas loading system. Once the tube is processed and gas-filled, the tubulation is pinched and welded for vacuum tightness. The thyratrons are loaded with xenon such that the tube pressure at operating temperature is in the range of 100 to 300 microns.

An exploded view of the tube assembly is shown in Figure 3. From the left are the cathode header and shield assembly, the ceramic body assembly, the graphite grid and graphite anode, and support assembly. The grid, a slotted graphite disc with an open area of 3 square centimeters, is mounted directly on the grid support flange. The first five tubes were fabricated without pyrolytic graphite coatings on the grid and anode. The molybdenum anode supporting structure is joined by a tantalum spacer assembly to the molybdenum seal flange. The graphite anode is threaded on the molybdenum support so that the anode-to-grid spacing is 1/8 to 3/16 of an inch. The tube envelope is 3 inches in diameter and is fabricated from a 94-percent alumina body.

Figure 4 is an exploded view of the cathode subassemblies showing the cathode header, cathode assembly, and evaporation shield. Evaporation shields, which surround the cathodes, were not fabricated for the first five tubes. Operation of a tube without the shield allows a measure of the effectiveness of the grid structure and its material with respect to tube drop and ability to inhibit grid emission.

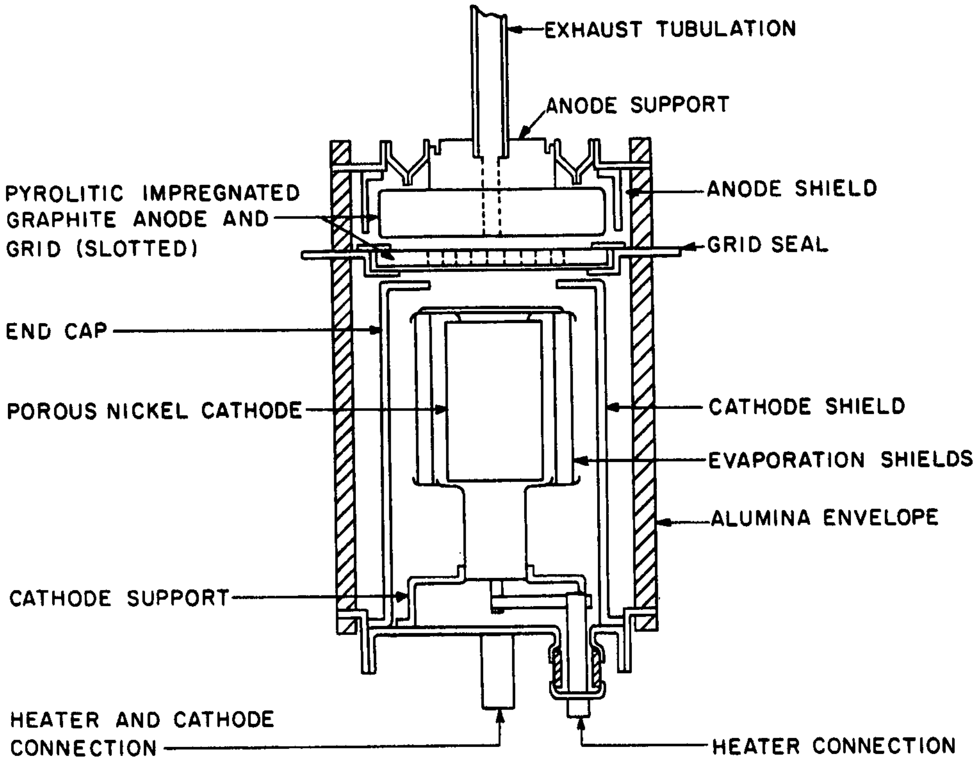

Figure 1 - Initial Thyratron Design

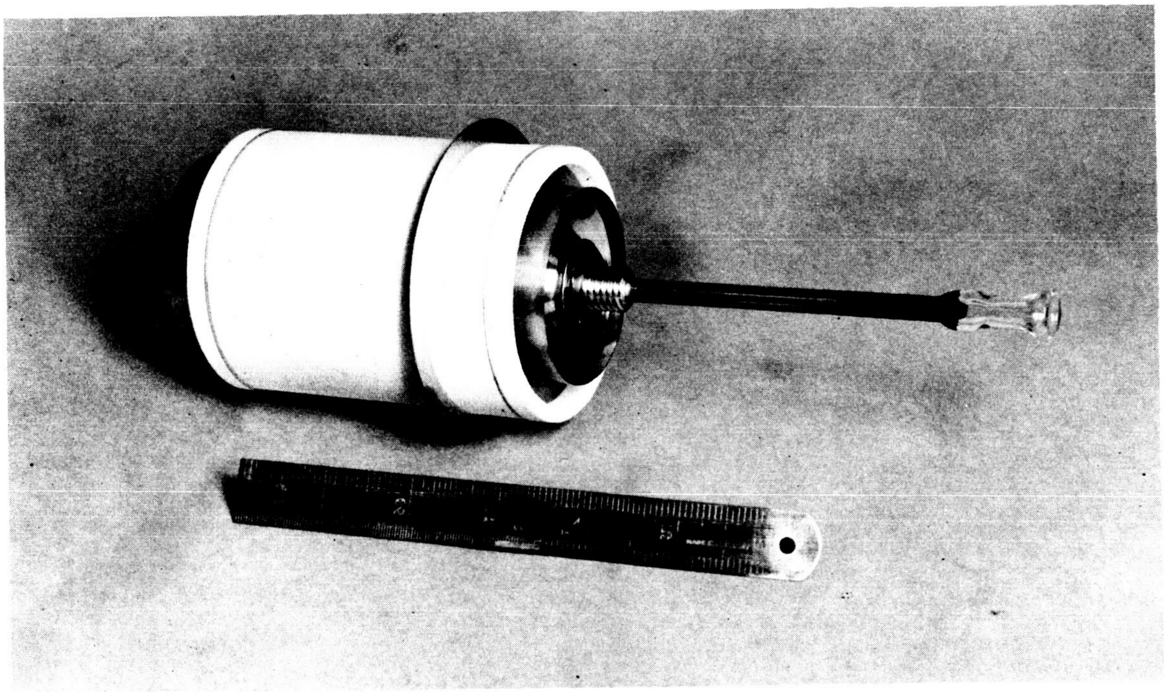

Figure 2 - Photograph of a High-Temperature Thyratron

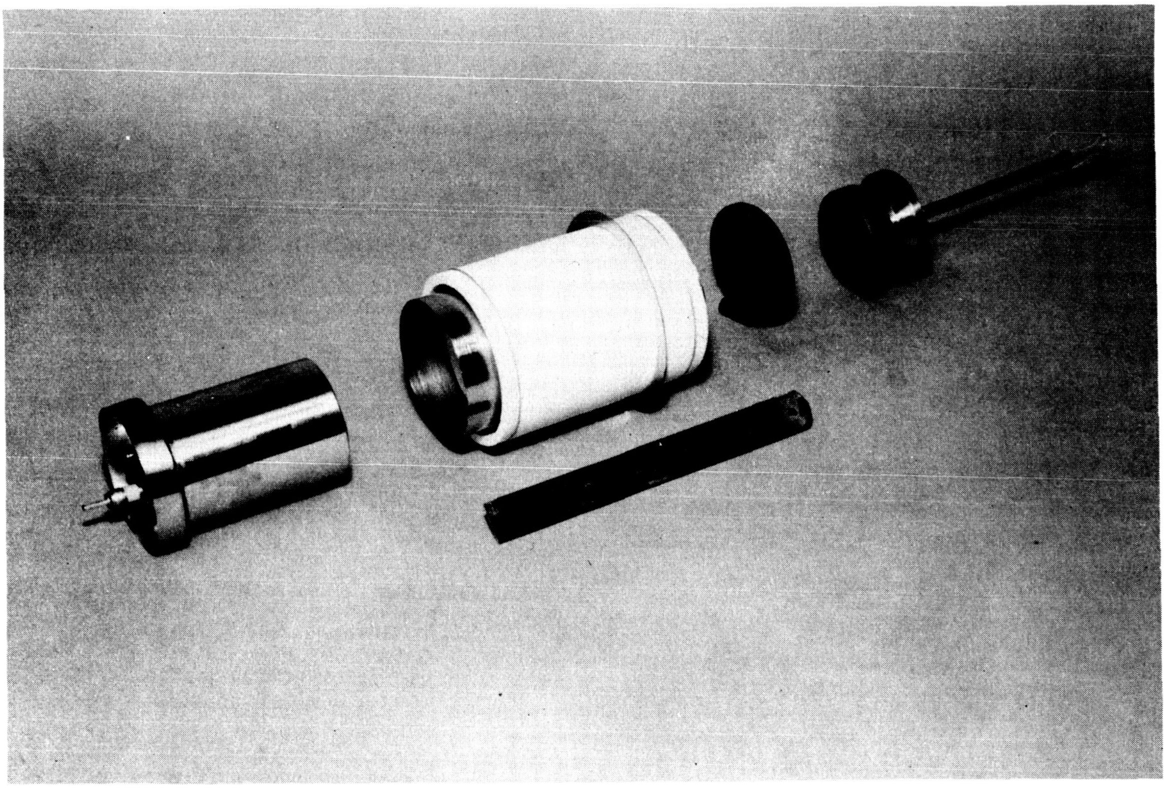

Figure 3 - Exploded View of Thyratron Assembly

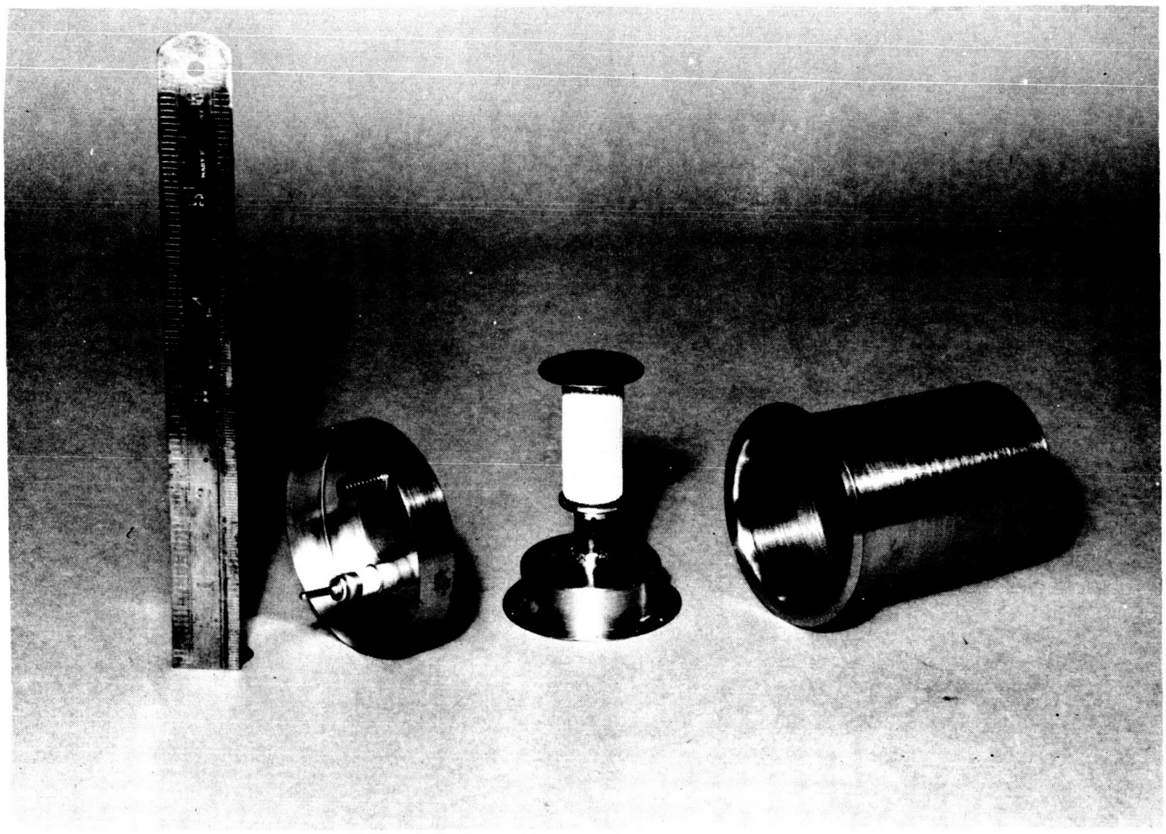

Figure 4 - Exploded View of Cathode Subassembly

Figures 5, 6 and 7 show modified versions of the initial design which are presently in progress. Figure 5 is a hollow anode structure designed to minimize gas clean-up by preventing sputtered anode material from impinging on the tube wall. This configuration causes material sputtered from one section of the anode to arrive at another and be resputtered, releasing gas trapped due to the initial sputtered material. Figure 6 is a photograph of the hollow anode assembly. It is planned to operate a structure of this type on endurance test.

The design configuration shown in Figure 7 has a cathode area of 70 square centimeters and is so designed that the cathode heater is external to the tube. The cathode consists of a vacuum-tight cylinder with ten fins brazed to the cylinder. The heater assembly is a tungsten heater wound on an alumina support. The heater leads are connected to ceramic pin seals which are welded into a subheader. This particular structure also lends itself to operation without a heater by mounting the cathode on a "hot" stud which would supply heat directly to the cathode. Initial tests will be made by inserting a radiation heater into the cathode cavity.

THYRATRON TESTS

The first high-temperature ceramic thyratron was put on test and operated for approximately three hours at 60 cycles with a wall temperature of 600°C. The maximum average current during this aging period was 10 amperes. The arc-drop (tube drop) at the start of test was 13.0 volts. However, after the tube was shut down and restarted the next day, the arc drop rose to 16.0 volts and subsequently the tube would not break down. Upon checking it was found that the tube had developed a leak at the brazed joint between the Fernico exhaust tubulation and the molybdenum anode support. The maximum anode temperature during this short operational run was 730°C. Inspection of the joint indicated that the braze was initially marginal.

During the operation of this tube, it was observed that there was electrical leakage between both the cathode-grid and grid-anode connections. Prior to removing the tube from the bell-jar test station, the grid-to-anode resistance measured 40,000 ohms at 640°C.

Subsequently, tube No. 2 was mounted in the test station. During the initial aging period, the arc drop was observed to be about 2.0 volts lower than tube No. 1. The measured drop at 5.0 amperes average was 11.5 volts at 600°C wall temperature. Electrical leakage between the tube

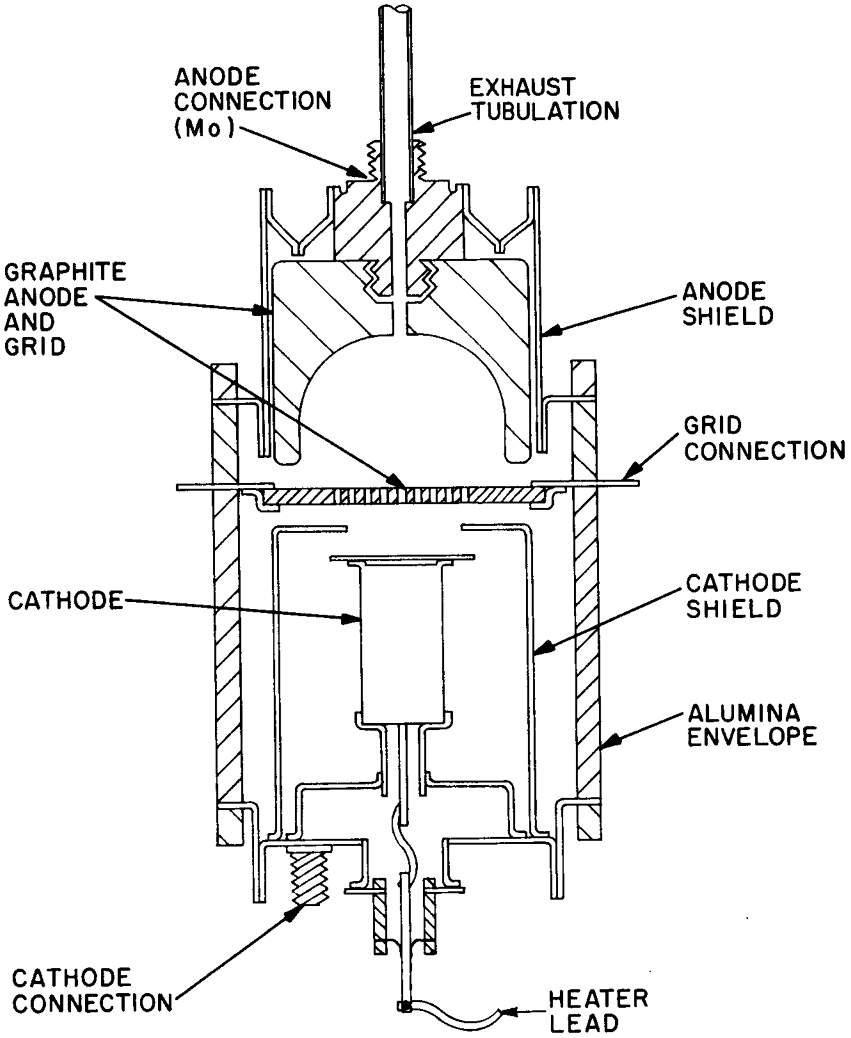

Figure 5 - Sketch of Hollow Anode Tube Structure

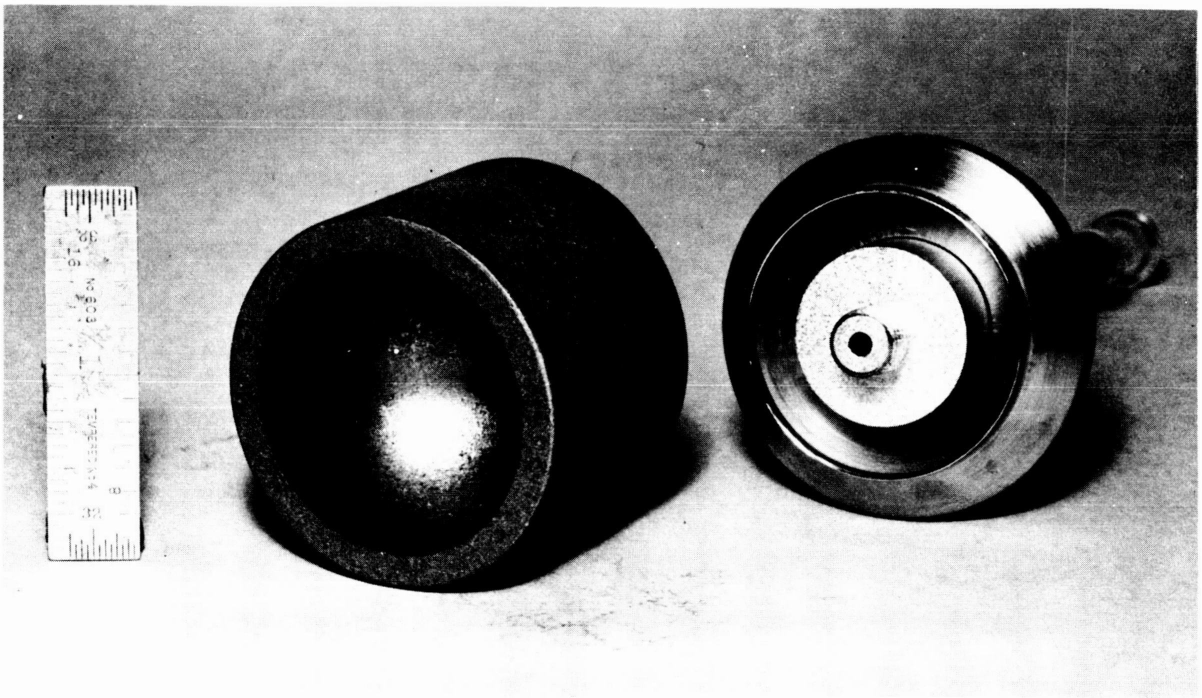

Figure 6 - Photograph of Hollow Anode Assembly

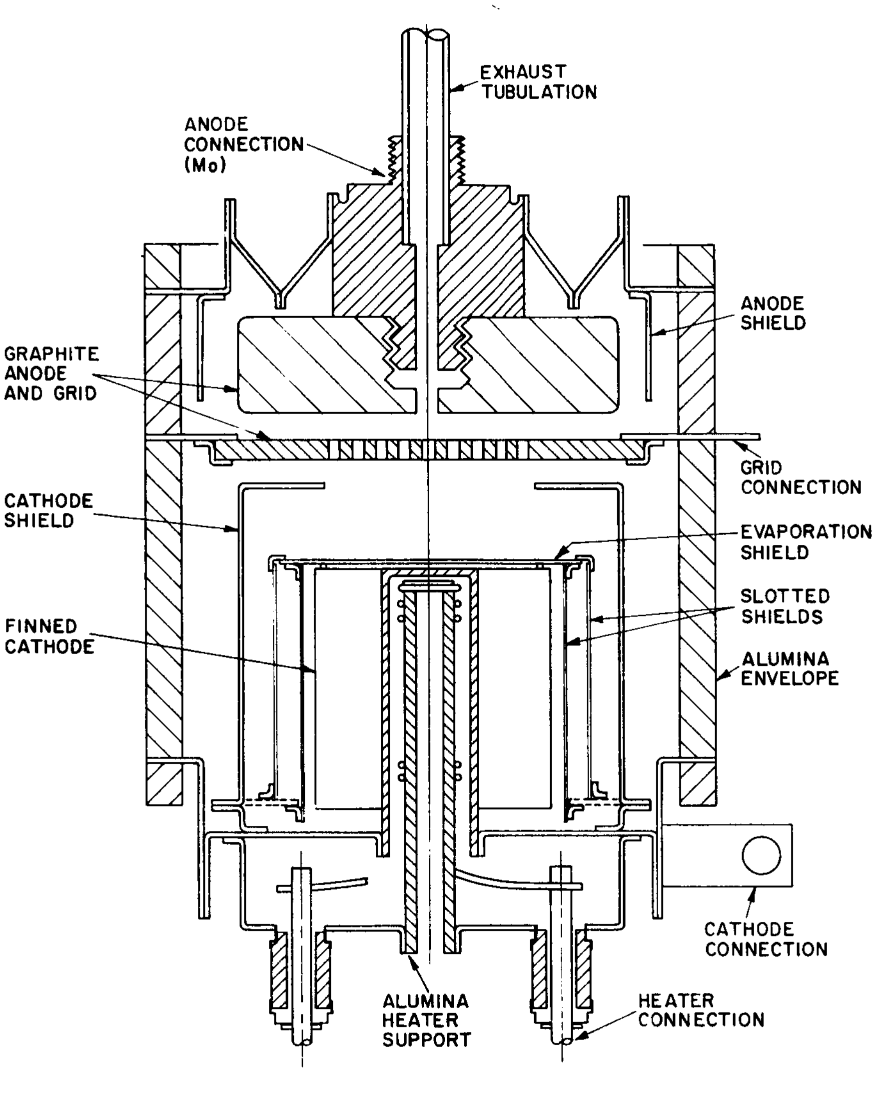

Figure 7 - Finned-Cathode Tube Structure

elements was also observed on this tube. A check of the resistance as a function of temperature was made on a body assembly that had been cleaned to remove any surface coating that might have accumulated due to handling. These data were compared to the leakage resistance of tube No. 2 as shown by the graph in Figure 8. The results are essentially the same between the two systems, except that the grid-anode resistance of the test body followed the grid-cathode resistance of tube No. 2. These results indicate that the electrical leakage is due to resistance changes in the bulk of the ceramic rather than surface effects. A test sample of the 94-percent alumina body, used on the initial tubes, and a 99-percent alumina (Lucalox*) sample is being prepared to evaluate differences in resistivity between the two types of ceramic bodies as a function of temperature. No data on resistivity are presently available on either of these ceramics. Relatively small amounts of impurity can make considerable variation in the resistance-temperature characteristics. The effect of grid-to-anode leakage on a thyratron is to increase the grid hold-off characteristics. As the anode voltage is increased, the grid voltage increases, requiring increased grid-bias voltage to prevent the tube from firing.

Tube No. 2 was operated for 80 hours at temperatures in excess of 500°C. Of this total, 20 hours were at frequencies greater than 400 cycles, and 10 to 15 hours at 3000 cycles. Because of the power limitations on the variable-frequency power oscillator (5 KVA) and associated transformer, the tube current was limited to 2.5 to 3.0 amperes during the high-frequency, high peak inverse voltage tests. Thyratron grid characteristics were measured over the wall temperature range of 550°C to 650°C, and at frequencies up to 3000 cycles. A nine-hour continuous test run was made at 1500 volts peak inverse, 2.0 amperes average, with the wall temperature at 600°C. The arc drop of 10 amperes average current at 60 cycles was checked before and after the run. The arc drop in each case was 13.5 volts, indicating no observable gas clean-up. Long-term operation is required before a definitive result can be obtained on gas clean-up characteristics.

A high-current (15 amperes average), low-voltage (175 volts peak) run was made over the range of 1000 to 3000 cycles per second to observe the recovery ability of the tube structure. During this test run, the tube wall temperature reached a maximum of 730°C while the anode measured 805°C. No recovery problems were evident during the 2-1/2-hour run and grid control was maintained during the entire run. These observations

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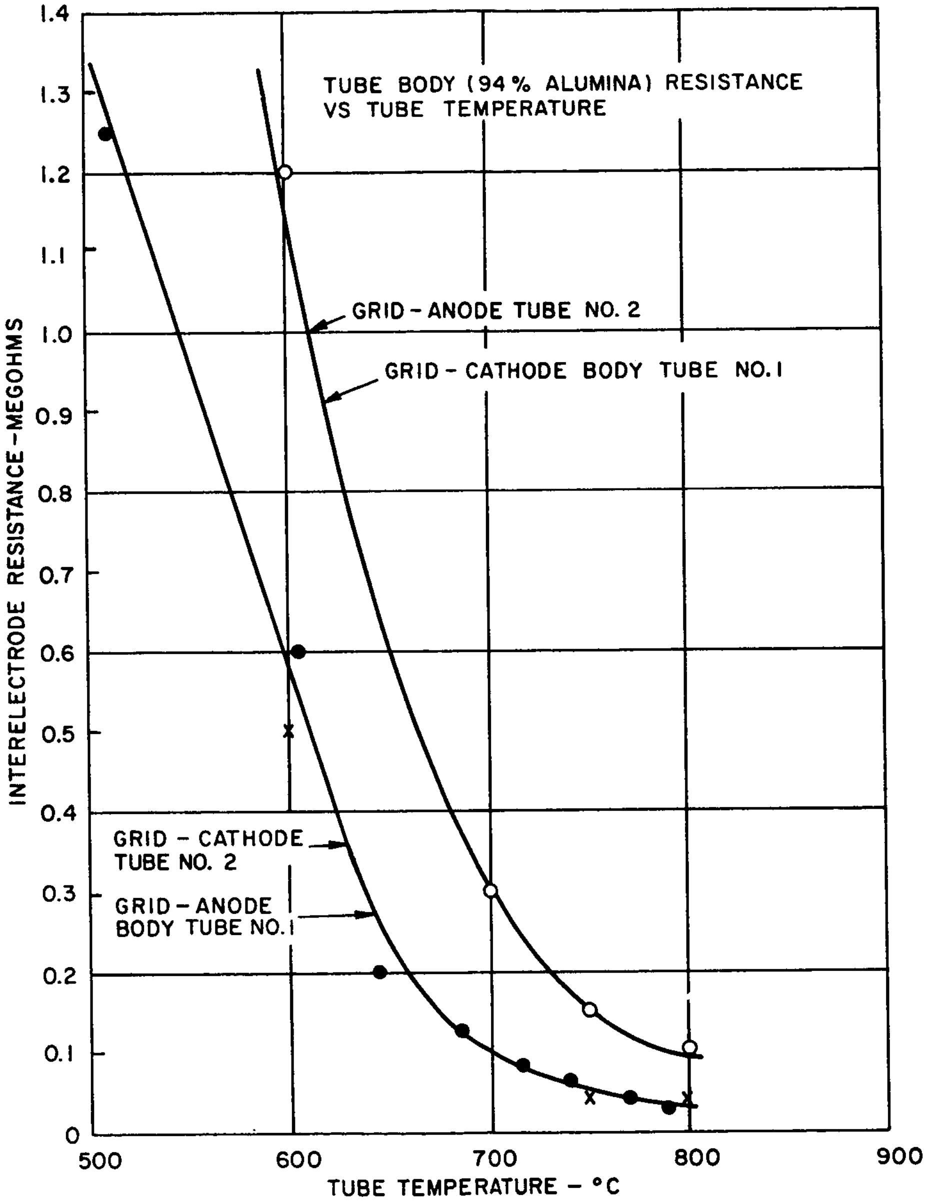

Figure 8 - Graph Showing Resistance of the Ceramic Tube Body

indicate that the deionization time of the grid-anode spacing is less than 150 microseconds. The maximum operational frequency depends on a number of factors which include electrode spacing, gas pressure, grid voltage, and tube current.

A series of dynamic grid characteristics was taken over a frequency range of 1000 cycles per second to 3000 cycles per second at tube wall temperatures of 550°C, 600°C, and 650°C. Tube current during these runs was held constant at 2.5 amperes average. The data were obtained while the tube was being used as a half-wave rectifier working into a resistive load of unknown inductance. Figures 9, 10 and 11 are plots of grid breakdown voltage measured across the grid with a DC voltmeter. The average anode temperature was essentially the same as the tube wall temperature during each set of measurements. A series of static DC grid breakdown characteristics was made, and the results are plotted in Figure 12. Under static conditions, the grid shows a positive control characteristic; while under dynamic conditions, the grid shifts to lower control voltages. This discrepancy is primarily due to the influence of the grid-to-anode leakage resistance. An AC voltage is superimposed on the DC grid bias due to the leakage resistance from grid-to-anode. The peak amplitude of the impressed AC is a function of the anode voltage. Subsequent data using peak values of grid voltage as measured on an oscilloscope are comparable to the static DC breakdown curves.

As previously mentioned, tube No. 2 was operated on test for over 80 hours. At the end of this period it was removed, and tube No. 3 was mounted in the same test station. The general operation of tube No. 3 was consistent with the operation of tube No. 2, repeating similar data. The maximum temperature during these tests was approximately 750°C.

At no time during the test period was there an indication of grid conduction or gas clean-up. Longer term testing is required for a more accurate evaluation.

VOLTAGE-REFERENCE TUBES

Ten voltage-reference tube bodies have been completed and four have been tested. Figure 13 is a photograph of one of the completed tubes. The tubes are now being processed on an ion-pump system which has been modified to accommodate the neon-gas loading system. The nominal final exhaust pressure during processing is approximately 7×10^{-8} Torr.

An automatic data recording system has been set up so that tube temperature, cathode temperature, tube current, and tube voltage can be simultaneously recorded. This system will be used during the 1000-hour endurance tests to measure tube operating characteristics. Figure 14 is a photograph of one of the reference-tube life-test stations. An 8-liter-per-second triode ion pump is shown on the left mounted through a vacuum flange to the exhaust port of the vacuum chamber. The valve located in the exhaust tubulation is used for rough pumping the system and as a bleeder valve for opening the system. A seven-pin ceramic feedthrough is welded into each of the six-inch diameter flanges mounted on the top and bottom of the vacuum bell jar. Figure 15 shows the individual high-temperature oven and how the tubes are mounted in the system. Two tubes are mounted in each station with one tube in an inverted position. It is planned to operate a third system in a horizontal position so that the tests will be made with tubes operating in three different positions. The internal tube connections are made through the supporting cover to the pin feedthrough welded into the center of the base plate. This system provides a maximum versatility in the testing proceedure. If a failure of one tube occurs, only one other tube has to be shut down, thereby minimizing delays in total time accumulation. Data on each of six tubes will be recorded periodically so that any changes during the 1000-hour test can be monitored. During the next period, two voltage-reference tubes will be started on the 1000-hour endurance test.

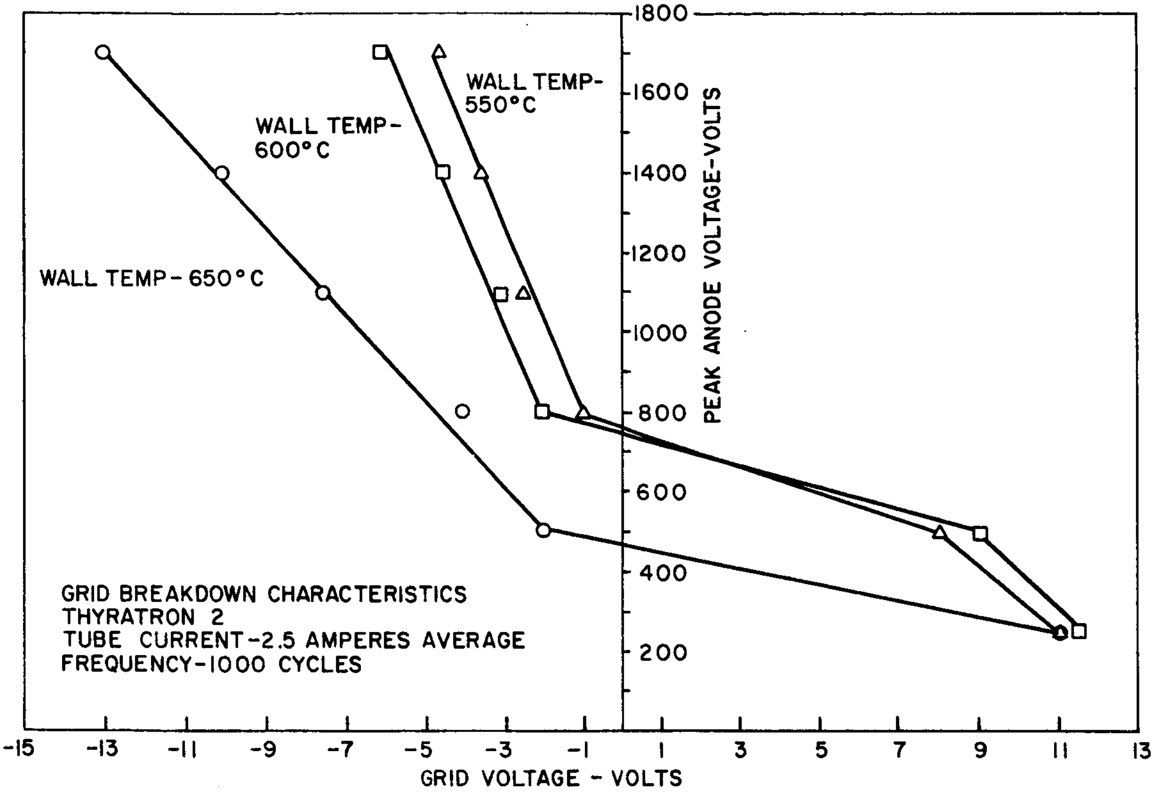

Figure 9 - Grid Breakdown Potentials at 1000 Cycles per Second

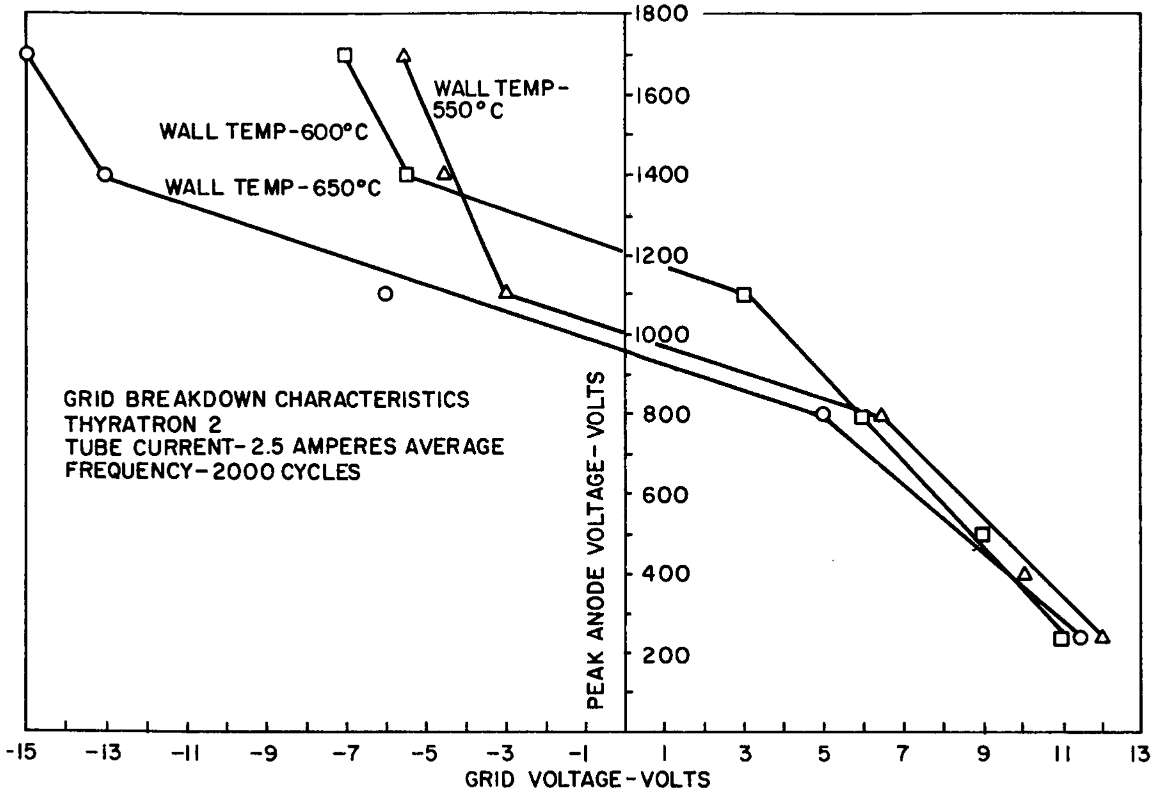

Figure 10 - Grid Breakdown Potentials at 2000 Cycles per Second

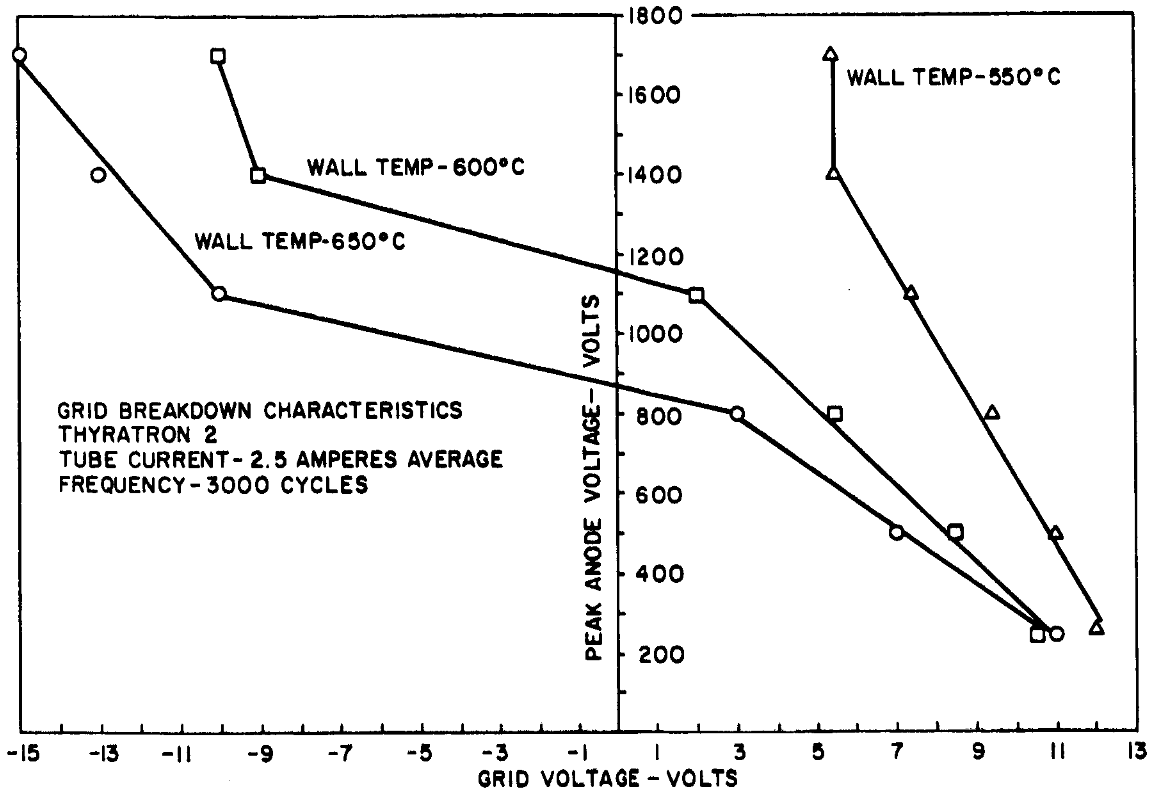

Figure 11 - Grid Breakdown Potentials at 3000 Cycles per Second

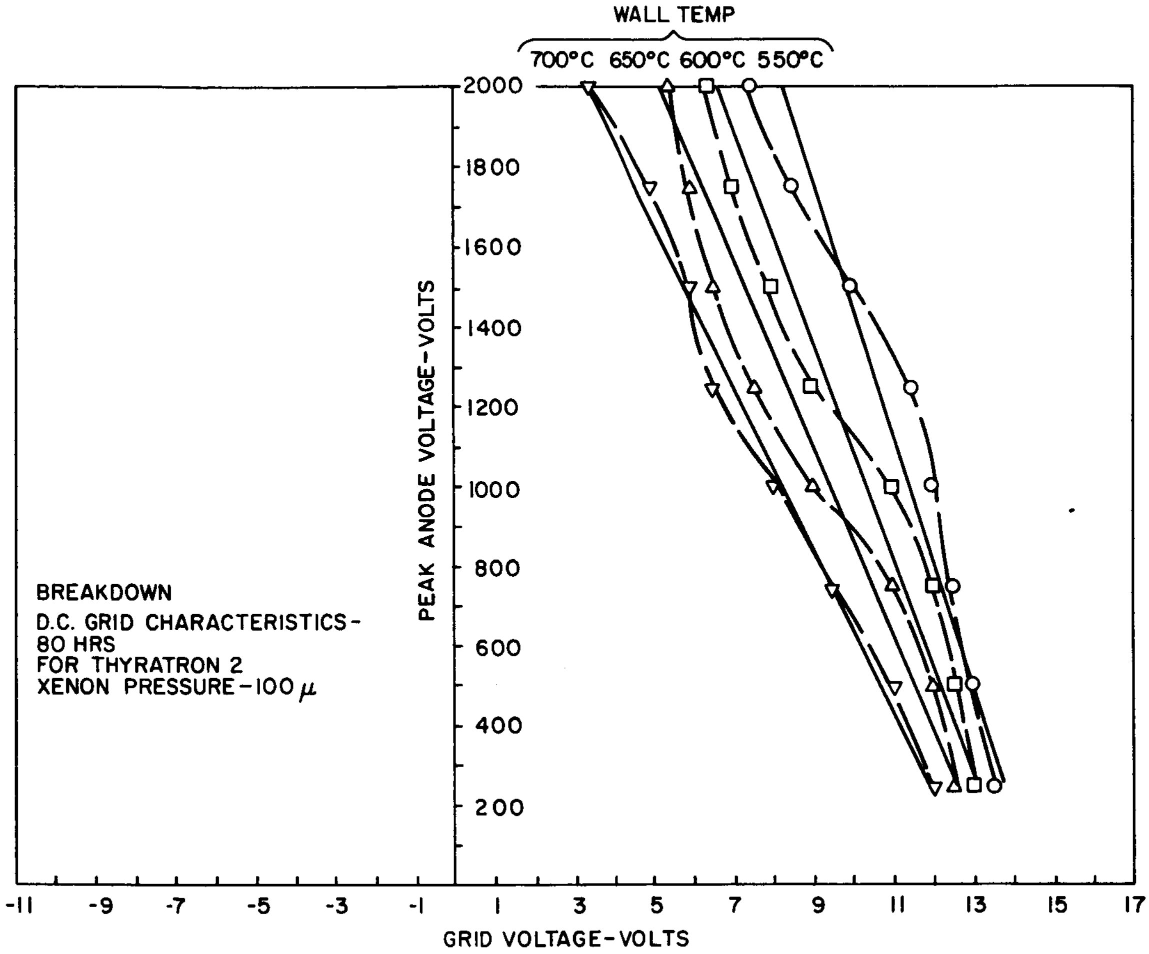

Figure 12 - DC Grid Breakdown Voltage

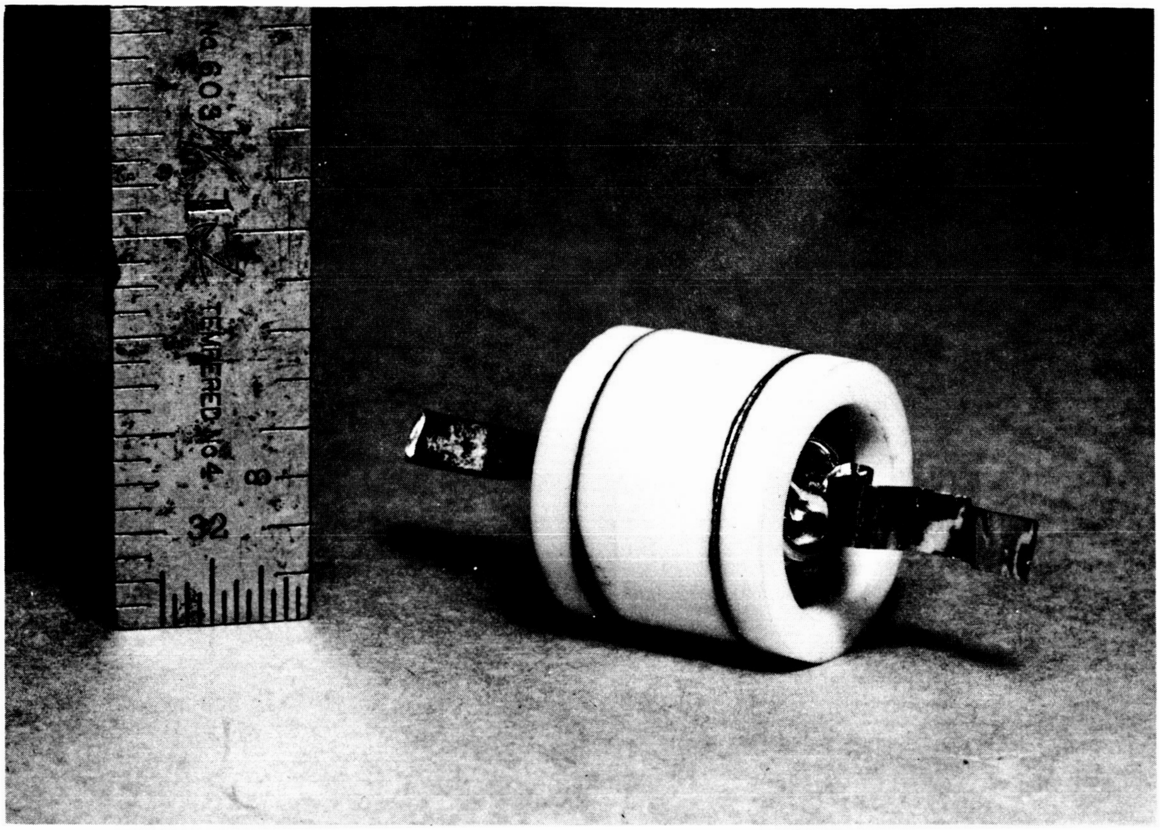

Figure 13 - Completed Voltage-Reference Tube

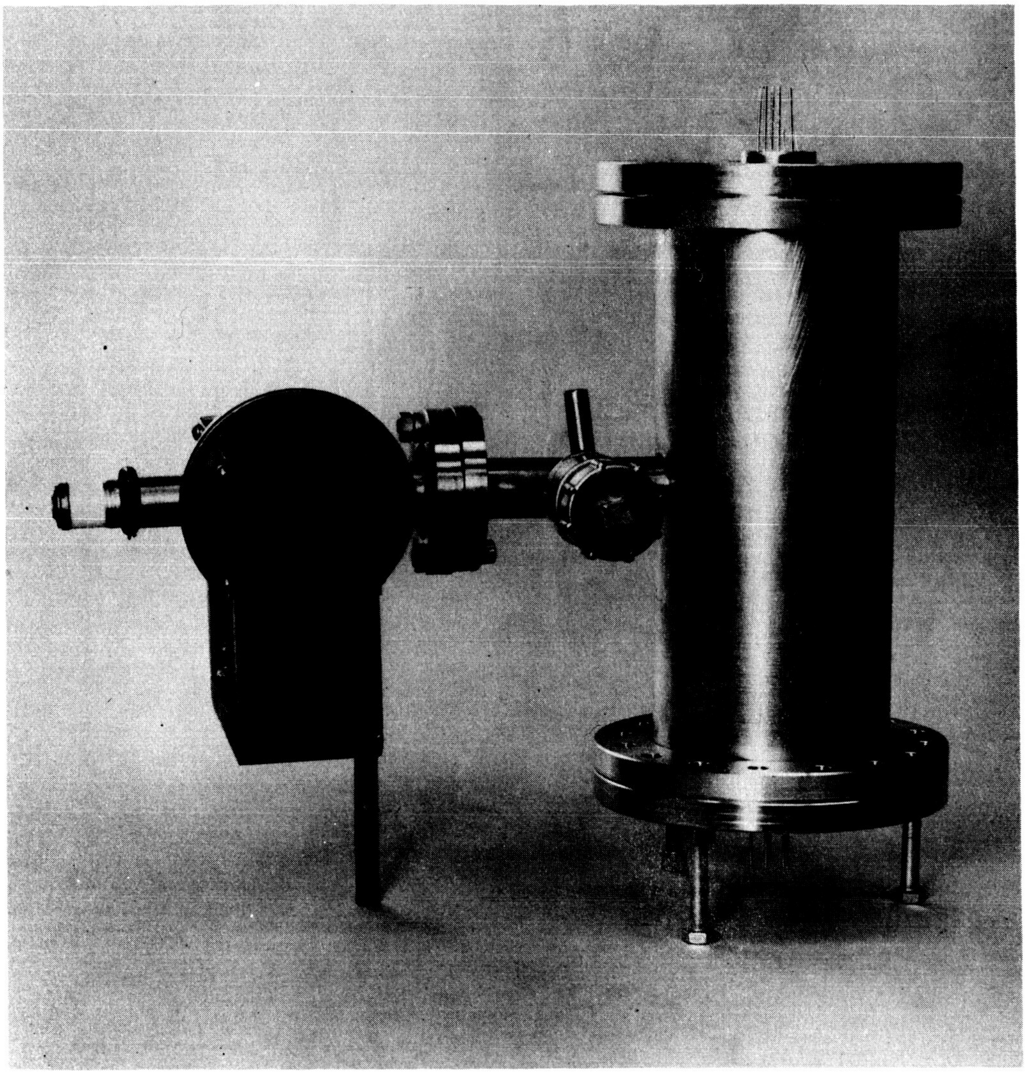

Figure 14 - Voltage-Reference-Tube Life-Test Station

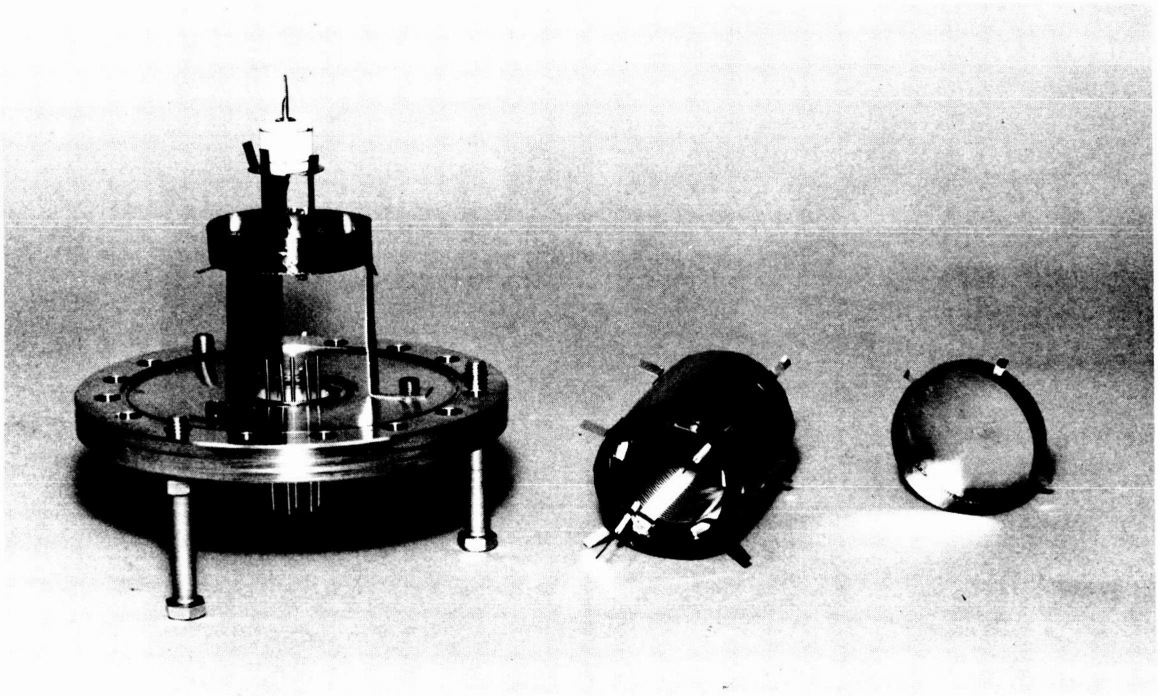

Figure 15 - High-Temperature Oven and Tube Mounting Within

PROGRAM FOR THE NEXT PERIOD

During the next period, more complete tube characteristics will be taken on the initial design thyratron structure. In addition, the hollow anode structure and finned-cathode design will be evaluated. Tests will also be made on a higher purity alumina ceramic tube body. After these evaluations are completed, a decision will be made as to which designs will be run on endurance test.

Endurance tests will be started on the voltage-reference tubes. Two tubes will be operated in each test station.

Development of

HIGH-TEMPERATURE, GAS-FILLED CERAMIC RECTIFIERS, THYRATRONS AND VOLTAGE-REFERENCE TUBES

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ABSTRACT

This report describes the work effort during the second quarter of Contract NAS3-6469. The completion of the first five thyratrons and ten voltage-reference tubes is described. Performance test programs of both tube types are initiated and the results are given.

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